AD-A271 249

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

ormation is estimated to average 1 hour per response including the time for reviewing instructions searching existing data sources completing and reviewing the collection of information Send comments regarding this burden estimate or any other aspect of this for reducing this burden to Washington Headquarters Services Directorate for Information Operations and Reports 1215 Jefferson 4302 and to the Office of Management and Budget Paperwork Reduction Project (0704-0188) Washington DC 20503

k)	2. REPORT DATE 30 June 1993	3. REPORT TYPE AND DATES COVERED Final: 1 May 1990 to 30 April 1993

4. TITLE AND SUBTITLE
Solid-State Dynamics in Novel Semiconductor Nanostructures

5. FUNDING NUMBERS
(2)
DAAL03-89-D-0003

6. AUTHOR(S)
M.A. Stroscio

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
M.A. Stroscio
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARO 28187.1-EL

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

759300

93-24974

13. ABSTRACT *(Maximum 200 words)*

This research program has focussed on selected aspects of the confinement of optical phonons in structured polar semiconductor structures as well as on the interaction of carriers with phonons in such structures.

93

14. SUBJECT TERMS	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

SOLID-STATE DYNAMICS IN NOVEL SEMICONDUCTOR NANOSTRUCTURES

FINAL REPORT

MICHAEL A. STROSCIO

30 JUNE 1993

U. S. ARMY RESEARCH OFFICE

DAAL03-89-D-0003-05

NORTH CAROLINA STATE UNIVERSITY

Statement of the Problem Studied

This research program has focussed on selected aspects of the confinement of optical phonons in structured polar semiconductor structures as well as on the interaction of carriers with phonons in such structures.

Summary of Key Results

During this research, a full theory for single-particle LO- and SO -phonon interactions in quantum wires was developed. A principal finding of the research was that electron--SO-phonon scattering dominates over electron--LO-phonon scattering in quantum wires with lateral dimensions less than about 60 Angstroms. In addition, substantial progress was made in understanding carrier coupling with interface and confined phonon modes in quantum-wire and metal-semiconductor structures. In addition, the influence of interface roughness was determined for quantum-wire structures.

In the second year of this effort, the investigators made a number of significant discoveries including: The fact that electrostatic and mechanical boundary conditions yield substantially different interface-optical phonon scattering rates in quantum wires; interface-optical phonons may contribute more to inelastic carrier scattering than confined phonons for confinement dimensions less than about 100 Angstroms; and the imposition of metal-semiconductor boundary conditions on interface-optical phonons may be used to eliminate or reduce inelastic scattering due to interface optical phonons. The last discovery portents numerous practical applications in nanoscale and mesoscopic electronic and optoelectronic devices.

During this same period, the investigators made a number of significant findings including: the fact that the imposition of metal-semiconductor boundary conditions on interface-optical phonons in quantum wells and quantum wires may be used to eliminate or reduce the inelastic scattering due to interface optical phonons; the fact that irregular cross sections in quantum wires can cause 1D electron scattering rates to reduce to the 3D results; the fact that phonon lifetime effects dominate over collective effects in carrier energy loss due to LO phonon emission in quantum wires; and the finding that phonon potentials for double barrier quantum wells approximate those for two-heterojunction structures for a wide range of dimensional parameters.

Macroscopic dielectric continuum models of optical-phonon modes predict enhancements in the magnitudes of the surface-optical (SO) modes in double-barrier heterostructures as the heterojunction-to-heterojunction separation is reduced. In this work, the ratio of electron scattering by the SO-phonon modes to that by the (electrostatic) confined longitudinal-optical-(LO-) phonon modes is calculated for a GaAs/AlAs short-period superlattice based on the assumption that electron-SO-phonon scattering may be described by a scalar potential.

The scaling of the ratio of electron-SO-phonon scattering to electron-LO-phonon scattering as function of the superlattice period provides a sensitive test of the appropriateness of the scalar-potential model. The effect of phonon confinement on electron-optical-phonon scattering rates is presented for rectangular quantum wires as well. A major conclusion of these new results is that it is essential to model phonon confinement properly in predicting carrier transport properties in mesoscale structures.

Novel quantum-effect polar-semiconductor devices underlie technologies portending dramatic enhancements in the capability to process information orders-of-magnitude faster than is possible currently. In many of these quantum-effect devices, charges are transported in quantum-well and quasi-one-dimensional quantum wires which must support the transport of changes at high mobilities. However, it has recently been demonstrated that longitudinal-optical (LO) phonons established at quantum-wire interfaces lead to dramatic enhancements in mobility-degrading carrier-phonon interactions. In novel mesoscopic de Broglie wave devices, LO phonons are confined in structures with complex geometries which frequently incorporate metal-semiconductor interfaces. Our recent work has resulted in a theory of confined and interface LO phonons in mesoscopic devices and metal-semiconductor interfaces in such a way as to dramatically reduce unwanted emission of interface LO phonons.

In the final year of this research program, the theory of confined and interface longitudinal-optical (LO) phonon interactions was applied to predict the scattering rate of carriers with interface LO phonons in short-period superlattices as well as to model the temperature dependence of exciton linewidths in III-V quantum wells. In addition, interface-LO-phonon assisted Gamma-X transitions were identified in short-period III-V superlattices based on the dielectric continuum model for phonons and a modified Kronig-Penney model for the superlattice Gamma and X mimibands. All of these models agree well with recent experiments done by the international community and they confirm our previous predictions of the importance of interface LO phonon interactions in narrow quantum well structures. Separate theoretical efforts have been directed at four additional problems: a shell model formulation of confined and interface LO phonon modes; a determination of the interface modes in cylindrical quantum wires encapsulated in metal; a calculation of the finite Thomas-Fermi screening length in metal-semiconductor systems; and the formulation of a model of acoustic mode confinement leading to modified piezoelectric interactions in nanostructures. This research culminated in an examination of the acoustic phonon modes in selected structured semiconductor devices.

Participating Scientific Personnel

Professor K. W. Kim, NCSU
Mr. Amit Bhatt, NCSU
Mr. Ulvi Erdogian
Mr. James C. Hall

List of Publications

A list of publications supported under this effort is at Attachment 1.

PUBLICATIONS

K. W. Kim, M. A. Stroscio and J. C. Hall, "Frequencies of Confined Longitudinal-Optical Phonon Modes in GaAs GaP Short-Period Superlattices," J. Appl. Phys., 67, 6179 (1990).

M. A. Stroscio, K. W. Kim and J. C. Hall, "Variation in Frequencies of Confined Longitudinal-Optical Phonon Modes due to Changes in the Effective Force Constants near Heterojunction Interfaces," Superlattices and Microstructures, 7, 115 (1990).

M. A. Stroscio, K. W. Kim, M. A. Littlejohn and H. Chuang, "Polarization Eigenvectors of Surface-Optical-Phonon Modes in a Rectangular Quantum Wire," Physical Review B, 42, 1488 (1990).

K.W. Kim and M.A. Stroscio, "Electron-Optical-Phonon Interaction in Binary/Ternary Heterostructures," Journal of Applied Physics, 68, 6289 (1990).

Michael A. Stroscio, K.W. Kim and S. Rudin, "Scattering Rate for Electron--LO-Phonon Interaction in Polar Semiconductor Quantum Wires," Superlattices and Microstructure, 7, 115 (1991).

Leonard F. Register, Michael A. Stroscio and Michael A. Littlejohn, "Conservation Law for Confined Polar-Optical Phonon Influence Functionals," accepted for publication in Phys. Rev., B44, 3850 (1991).

K.W. Kim, M.A. Stroscio, A. Bhatt, V. V. Mitin and R. Mickevicius, "Electron-Optical-Phonon Scattering Rates in a Rectangular Semiconductor Quantum Wire," J. Appl. Phys., 70, 319 (1991).

K.W. Kim, M.A. Stroscio and J.C. Hall, "Frequencies of Confined Longitudinal-Optical Phonon Modes in Short-Period Strained Semiconductor Superlattices," Proceedings of the International Society of Optical Engineering, 1336, 43 (1990).

Michael A. Stroscio, K.W. Kim and M.A. Littlejohn, "Theory of Optical-Phonon Interactions in a Rectangular Quantum Wire," Proceedings of the International Society of Optical Engineering, 1362, 566-579, (1991).

Michael A. Stroscio, Gerald J. Iafrate, K. W. Kim, M. A. Littlejohn, Herbert Goronkin and George Maracas, "Transition from LO-Phonon to SO-Phonon Scattering in Short-Period AlAs-GaAs Superlattices," Applied Physics Letters, 59, 1093 (1991).

R. Mickevicius, V. V. Mitin, K. W. Kim, Michael A. Stroscio, and Gerald J. Iafrate, "Electron Intersubband Scattering by Confined and Localized Phonons in Real Quantum Wires," J. Phys.: Condens. Matter, 4, 4959 (1992).

H. L. Grubin T. R. Govindan, B. J. Morrison, D. K. Ferry and M. A. Stroscio, "Temperature Description of Transport in Single and Multiple Barrier Structures," Semiconductor Science and Technology, 7, B360 (1992).

H. L. Grubin, T. R. Govindan, B. J. Morrison and M. A. Stroscio, "Density Matrix and Quantum Moment Studies of Single and Multiple Barrier Structures," accepted for publ. in Semiconductor Science and Technology, 7, B434 (1992).

K. W. Kim, M. A. Littlejohn, M. A. Stroscio and G. J. Iafrate, "Transition from LO-Phonon to SO-Phonon Scattering in Short-Period AlAs-GaAs Superlattices and Scaling of Phonon Scattering Rates in Mesoscale Structures," Semiconductor Science and Technology, 7, B49 (1992).

R. Mickevicius, V. Mitin, K. W. Kim, and Michael A. Stroscio, "Electron High-Field Transport in Multi-Subband Quantum Wire Structures," Semiconductor Science and Technology, 7, B299 (1992).

S. Das Sarma, Michael A. Stroscio and K.W. Kim, "Dynamical Screening and Phonon Renormalization Effects in Quantum-Wire Transport Processes," Semiconductor Science and Technology, 7, B60 (1992).

Michael A. Stroscio, Gerald J. Iafrate, K. W. Kim, Harold L. Grubin, M. A. Littlejohn, V. V. Mitin and R. Mickevicius, "Nanostructure and Mesoscale Devices: The Role of LO-Phonon Interactions," Nanostructures and Mesoscopic Systems, (Academic Press) 379 (1992).

R. Mickevicius, V. V. Mitin, K. W. Kim and Michael A. Stroscio, "Electron Intersubband Scattering in Real Quantum Wires," Superlattices and Microstructures, 11, 277 (1992).

Michael A. Stroscio, K. W. Kim, Gerald J. Iafrate, Mitra Dutta and Harold L. Grubin, "Dramatic Reduction of the Longitudinal-Optical Phonon Emission Rate in Polar-Semiconductor Quantum Wires," Philosophical Magazine Letters, 65, 173 (1992).

T. A. Gant, M. Dutta, G. K. Reid, N. A. El-Masry, S. M. Bedair, and M. A. Stroscio, "A Raman Study of Ordering in GaInP, Phys. Rev. B, 46, 3834 (1992).

H. Shen, M. Dutta, R. Moerkirk, D. M. Kim, K. W. Chung, P. P. Ruden, M. I. Nathan and M. A. Stroscio, "Direct Measurement of Piezoelectric Fields in a (111)B-Grown InGaAs/GaAs Heterostructure by Franz-Keldysh Oscillations," Appl. Phys. Lett., 60, 2400 (1992).

H. Qiang, Fred H. Pollak, C. Sotomayor Torres, W. Leitch, Michael A. Stroscio, Gerald J. Iafrate and K. W. Kim, "Size Dependence of the Electron-Phonon Coupling in GaAs/Ga(0.7)Al(0.3)As Single Quantum Wells," Appl. Phys. Lett., 61, 1411 (1992).

K. W. Kim, A. R. Bhatt, Michael A. Stroscio, P. J. Turley and S. W. Teitsworth, "Effects of Interface Phonon Scattering in Multi-Heterointerface Structures," J. Appl. Phys., 72, 2282 (1992).

A. R. Bhatt, K. W. Kim, M. A. Stroscio, G. J. Iafrate, M. Dutta, H. L. Grubin, R. Haque and X. T. Zhu, "Reduction of LO-Phonon Interface Modes Using Metal-Semiconductor Heterostructures," J. Applied Physics, 73, 2338 (1993).

Michael A. Stroscio, K. W. Kim, A. R. Bhatt, Gerald J. Iafrate, Mitra Dutta and Harold L. Grubin, "Reduction of Inelastic Longitudinal-Optical Phonon Scattering in Narrow Polar-Semiconductor Quantum Wells," Proceedings of the SPIE, 1675, 237 (1992).

M. U. Erdogan, K. W. Kim and M. A. Stroscio, "Effects of Band Mixing on Hole Tunnelling Times in GaAs/AlAs Double-Barrier Structures," Appl. Phys. Lett., 62, 1423 (1993).